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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF A VARIABLE-AREA
AUXILIARY AIR-INTAKE SYSTEM AT
MACH NUMBERS FROM 0 TO 1.3

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and John T. Swift

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SUMMARY

A variable-area auxiliary air scoop in combination with a fixed-area nose intake was tested at Mach numbers from 0 to 1.3. The purpose of the investigation was to evaluate the effectiveness of such an auxiliary intake in improving the net thrust of an intake-engine combination over a range of speeds. The results indicated that the internal flow was always stable and that improvements in net thrust would be realized at Mach numbers up to about 1.1 for an intake design Mach number of 1.3.

INTRODUCTION

The optimum inlet area of air intakes for most turbojet engines varies with flight Mach number and altitude. Although it is possible to operate an airplane or engine without varying inlet area, such operation usually incurs large thrust losses which limit operational flexibility and performance. Previous investigations of air intakes designed for Mach numbers near 2.0 have shown that variable inlet-area systems will minimize the thrust losses of intake-engine combinations when operating at off-design conditions, and several variable-area designs have been proposed. (See refs. 1 to 5.) Since it is likely that engines with fixed-area intakes designed for transonic speeds will also suffer losses in thrust at off-design conditions, calculations were made to determine the magnitudes of these losses. The methods of reference 6 were used in the calculations. An engine with air-flow characteristics similar to those of the J57-P-1 operating at normal-rated conditions, inlets of the normal-shock type, and a maximum flight Mach number and

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altitude for the engine operating condition were selected. It was also assumed that the difference between the cowl-suction force and the additive drag is that given by Fraenkel (ref. 7) and that the subsonic diffusion was isentropic. The results of the calculations, in terms of (1) percent thrust loss due to off-design operation and (2) percent increase in inlet area that would provide the additional air for optimum engine operation, are shown in the following table:

Intake design Mach No. ¹	Flight Mach No.	Percent thrust loss due to off-design intake operation	Percent increase in inlet area to maintain zero thrust loss
1.3	1.3	0	0
	1.1	9	5
	.9	18	13
	.7	28	30
0.9	1.3	5	--
	1.1	1	--
	.9	0	--
	.7	8	--

¹Design altitude = 35,000 feet

For a design Mach number of 1.3, the intake would operate supercritically (at the maximum mass-flow ratio) at all lower Mach numbers, resulting in thrust losses due to low pressure recovery. For a design Mach number of 0.9, the intake would operate subcritically (at less than maximum mass-flow ratio) at the higher Mach numbers, resulting in thrust losses due to additive drag. At 0.7 Mach number, the intake designed for 0.9 Mach number would operate supercritically and the thrust loss would be due to low pressure recovery. Since the margin of excess thrust is generally the least in the transonic speed range, thrust losses such as those indicated in the table are undesirable. The effect of altitude was also considered in the calculations and it was found that for fixed inlet areas the thrust losses due to off-design altitudes could be as great as those due to off-design Mach numbers. Thus, in the transonic-speed range, a need exists for a variable-area intake for use with turbojet engines having air-flow characteristics similar to those of the J57-P-1.

A study was made of several variable-area intakes that could be used at transonic speeds to determine the most suitable type. It was found that a variable-area auxiliary intake, in combination with a fixed-area main intake, was more compact and therefore probably lighter in weight and less complex than any of the variable main-intake systems considered. As a result, an auxiliary air-intake system was selected

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for investigation. The purpose of the investigation was to determine the performance of a scoop-type variable-area auxiliary inlet at sub-sonic and transonic speeds. The pressure recovery and mass-flow ratio of the internal flow were measured, but no drag measurements were made because the additional complication of the test apparatus was not believed to be justified for a preliminary investigation. The results of the tests and an evaluation of the data in terms of a thrust ratio are given in this report.

NOTATION

A cross-sectional area, sq ft

A_{2a} outlet area of auxiliary intake at station 2, sq ft
(See fig. 1.)

C_F effective thrust ratio, $\frac{F_i - D_{pre}}{F_{isen}}$, dimensionless

d distance from bottom of basic duct, in.

D_{pre} drag, $(p_w - p_o) [(A_1 + A_{1a}) - A_{oT}]$, lb
(See ref. 7.)

w auxiliary-inlet-flap width, in.

F_i internal thrust, lb
(See ref. 6.)

F_{isen} internal thrust based on 100-percent pressure recovery, lb

H total pressure, lb/sq ft, absolute

h one-half of duct height in vertical plane, in.

M Mach number, dimensionless

m mass-flow rate, $\rho V A$, slugs/sec

m_o mass-flow rate based on inlet area, $\rho_o V_o A_1$, slugs/sec

p static pressure, lb/sq ft, absolute

r local internal-duct radius, in.

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s chord of arc described by apex of auxiliary inlet flap, in.
v velocity, ft/sec
x station downstream of main-duct entrance, in.
y one-half of duct width in horizontal plane, in.
α angle of attack, deg
β angle between main-duct horizontal center plane and center plane of inner auxiliary-inlet flap, deg
θ angle between main-duct horizontal center plane and center plane of outer auxiliary-inlet flap, deg
ρ mass density, slugs/cu ft

Subscripts

a auxiliary
b bottom
w conditions just downstream of normal shock wave
ref reference
t top
T total
o free stream
1 main-inlet-entrance station
1a auxiliary-inlet-entrance station
2 outlet station of auxiliary duct
3 diffuser-exit and survey-rake station
4 upstream mass-flow-measurement station
5 downstream mass-flow-measurement station
* maximum theoretical value
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APPARATUS AND TESTS

Wind Tunnel

The tests were conducted in the Ames 2- by 2-foot transonic wind tunnel. This wind tunnel is of the closed-circuit, variable-density type and utilizes a perforated test section to allow continuous operation from subsonic to supersonic Mach numbers. A centrifugal compressor in the wind-tunnel auxiliary equipment was used to induce the air flow through the model.

Model

The model tested in the present investigation is shown in figures 1 and 2. Both the nose and auxiliary inlets are of the normal-shock type. The auxiliary inlet consists of two flaps which span the main duct as shown in figure 1, and was designed to satisfy the following relation at each flap position:

$$\left(\frac{A_1}{A_2 - A_{2a}} \right) = \left(\frac{A_{1a}}{A_{2a}} \right)$$

The maximum opening occurred when these ratios were unity. The variation of internal cross-sectional area of the duct with axial distance is shown in figure 3. The dashed lines in the figure represent the longitudinal distribution of area remaining in the main duct for the various auxiliary-inlet openings that were tested.

Tests and Instrumentation

Average total-pressure recovery, mass-flow ratio, and diffuser total-pressure profiles in one plane were measured in the model at Mach numbers of 0, 0.20, 0.77, 0.95, 1.13, and 1.30 at 0° and 4° angle of attack. The 68-percent auxiliary-inlet opening, however, was not tested at Mach numbers above 0.20.

The total-pressure recovery and mass-flow ratios were determined from static-pressure measurements made at two adjacent stations of different cross-sectional areas in the duct (stations 4 and 5 in fig. 1). The accuracy of the method of mass-flow and pressure recovery measurement is dependent upon the local Mach number at station 5, the area ratio of the contraction, the individual accuracies of the static

pressure measurements, and the assumption of isentropic flow between the measurement stations. Consideration of these factors in the present experiments indicates maximum probable errors of ± 0.01 and ± 0.02 for the pressure-recovery and mass-flow ratios, respectively.

RESULTS AND DISCUSSION

The test data are presented in the order of increasing Mach number in figures 4 to 13. The data are given in plots of total-pressure recovery as a function of mass-flow ratio (figs. 4, 6, 8, 10, 12, and 13) and as total-pressure profiles across the duct at station 3 (figs. 5, 7, 9, and 11). The internal flow was stable at all test conditions and the effect of angle of attack (4°) was generally within the experimental accuracy and has not been shown in the figures.

The mass-flow data at zero Mach number (fig. 4) are given in percent of the theoretical value for choked flow with uniform velocity at the inlet station. It is interesting that the data for this test condition are correlated by the parameter m_T/m_{T*} , thus indicating that the losses in the main and auxiliary intakes are about equal.

The total-pressure recovery at a Mach number of 0.77 (fig. 8) is maintained above a value of 0.95 at high mass-flow ratios with the 24-percent auxiliary-inlet opening. Smaller auxiliary-inlet openings, however, decreased the total-pressure recovery at mass-flow ratios representing equal percentages of the theoretical maximum mass-flow ratios. This decrease is believed to be due to the increasing percentage of body boundary layer in the auxiliary-intake mass flow. This effect could be reduced by using an auxiliary intake of smaller width-to-height ratio, thus reducing the percentage of boundary layer for a given percent opening.

The pressure recovery for all auxiliary-intake openings at Mach numbers of 0.95 (fig. 10) and above, at mass-flow ratios representing equal percentages of the theoretical maximum mass-flow ratios, is less than that with the auxiliary intake closed. The maximum mass-flow ratios were less than the theoretical values at all Mach numbers. Although the body boundary layer is probably the major factor in limiting the pressure recovery and mass flow for the small inlet openings, the losses for the 24-percent opening cannot be attributed entirely to the boundary layer. It seems reasonable that the steep internal-surface slope of the external flap of the auxiliary intake at the larger openings would result in a detached normal shock wave at transonic speeds. This could cause reductions in both maximum pressure recovery and mass-flow ratio. Such an effect could be reduced by designing auxiliary intakes with the lips more nearly aligned with the local stream lines.

Evaluation of the Intake System for a Design Mach Number of 1.3

The effective thrust ratio (C_F) of the intake system tested was obtained by determining the engine net thrust by the method of reference 6, assuming the same engine operating conditions as were mentioned in the Introduction, and by assuming that the difference between the additive drag and the thrust component of the cowl-pressure force is that given by Fraenkel (ref. 7). The external drag of the intakes near the maximum mass-flow ratios was assumed to be constant and small, and therefore was not considered in the evaluation. This latter assumption is believed to be justified because the external-surface slopes of the auxiliary intake are small (2° to 4°) and at the design points of interest the mass-flow ratios of both intakes are near unity. The effective-thrust ratio was computed from the test data for a design altitude of 35,000 feet and is given as a function of Mach number in figure 14. Values of the ratio for the main intake only, when it is assumed to have variable inlet area, are also shown in figure 14 for comparison purposes. The results indicate that the auxiliary intake tested will provide increases in the effective-thrust ratio up to a Mach number of about 1.1 for an intake design Mach number of 1.3.

CONCLUDING REMARKS

Variable, scoop-type, auxiliary-air intakes can provide improvements in net thrust of an intake-engine system if the additional external drag is small. Improvements in the performance of auxiliary intakes at supersonic speeds can probably be obtained by minimizing the boundary-layer effect for small openings and by more nearly alining the lips of the auxiliary intake with the local stream lines.

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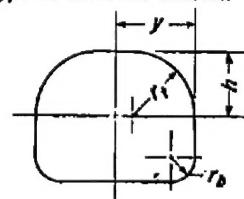
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Basic duct dimensions

<i>x</i>	<i>y</i>	<i>h</i>	<i>r₁</i>	<i>r_b</i>
0	0.812	0.812	0.812	0.812
1.60	0.816	0.799		0.781
3.20	0.828	0.799		0.722
4.80	0.845	0.800		0.624
6.40	0.915	0.803		0.488
8.00	1.034	0.804		0.312
9.60	1.156	0.805		0.033
10.24	1.197	0.806	0	
11.50		0.855	0.855	0.168
13.00		0.921	0.921	0.368
14.50		0.987	0.987	0.568
16.00		1.053	1.053	0.768

Typical internal section*Auxiliary inlet dimensions*

<i>A_{in}/A₁</i>	θ Degrees	β Degrees	<i>s_{1a}</i> Inches	<i>w_{1a}</i> Inches	<i>s_{2a}</i> Inches	<i>w_{2a}</i> Inches
0.05	3°18'	5°33'	0.054	1.850	0.070	2.319
0.12	4°46'	7°08'	0.138		0.168	2.318
0.24	7°21'	9°28'	0.268		0.293	2.316
0.68	16°08'	15°08'	0.760		0.595	2.312

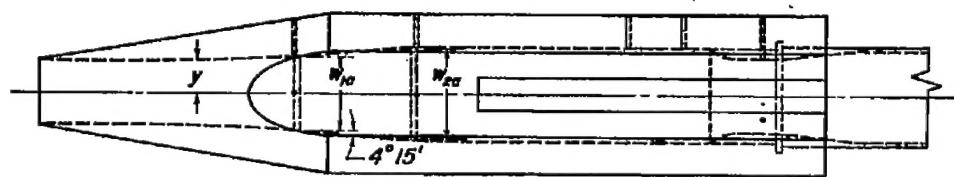
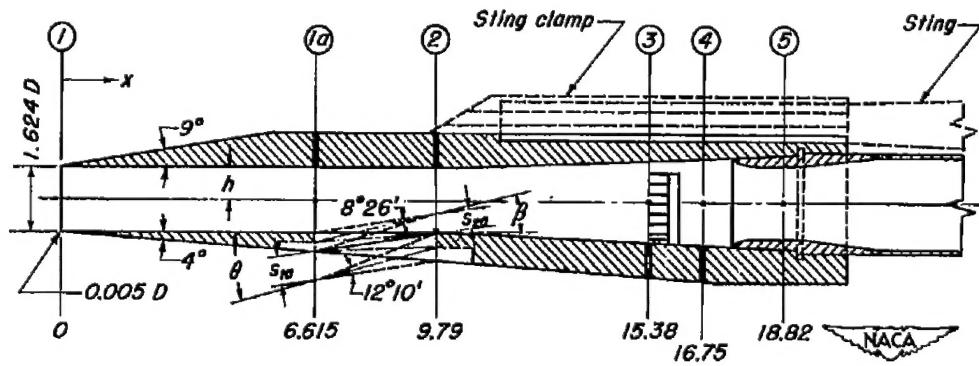
*All linear dimensions in inches*

Figure 1. - Model dimensions.

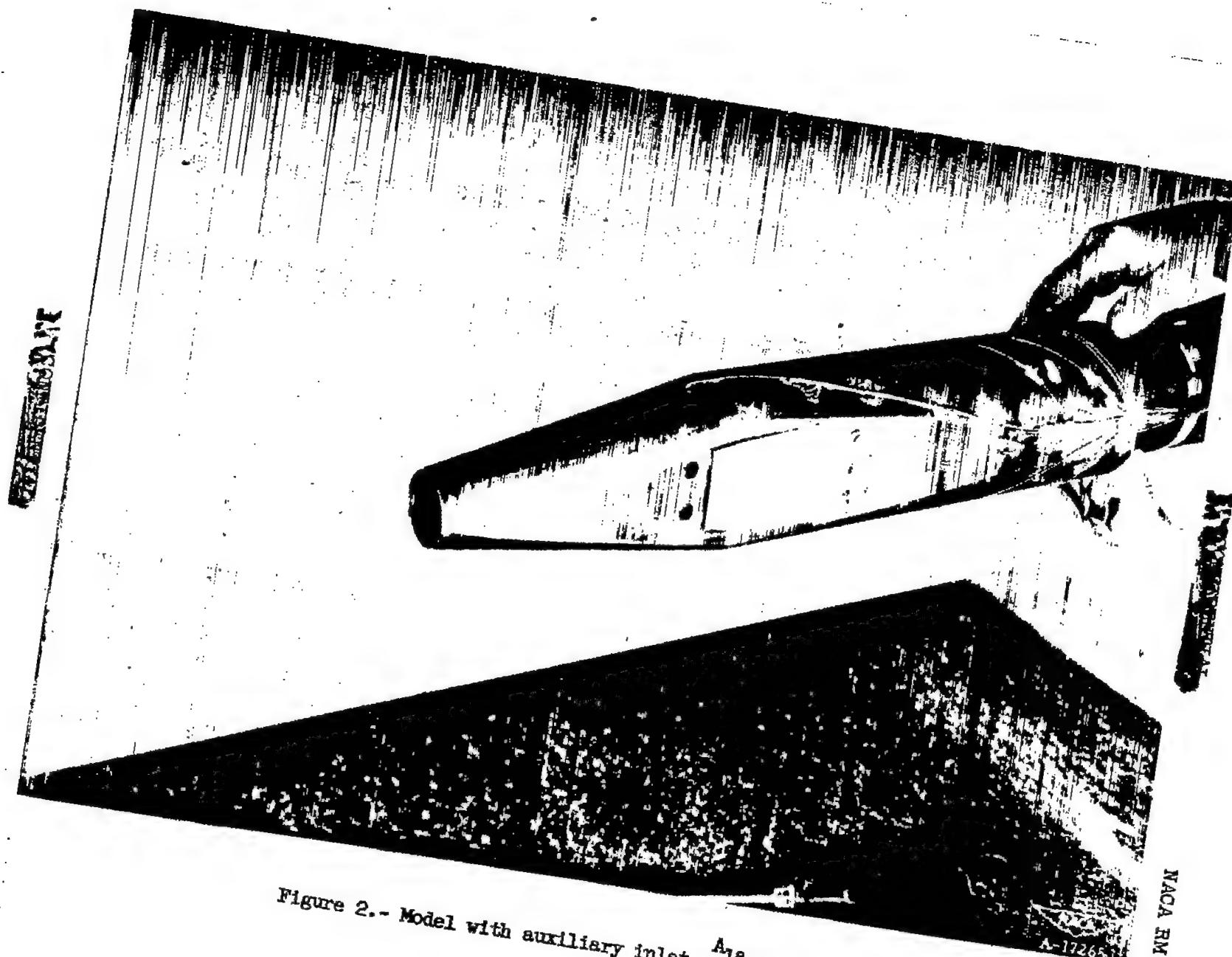


Figure 2.- Model with auxiliary inlet, $\frac{A_{1a}}{A_1} = 0.12$.

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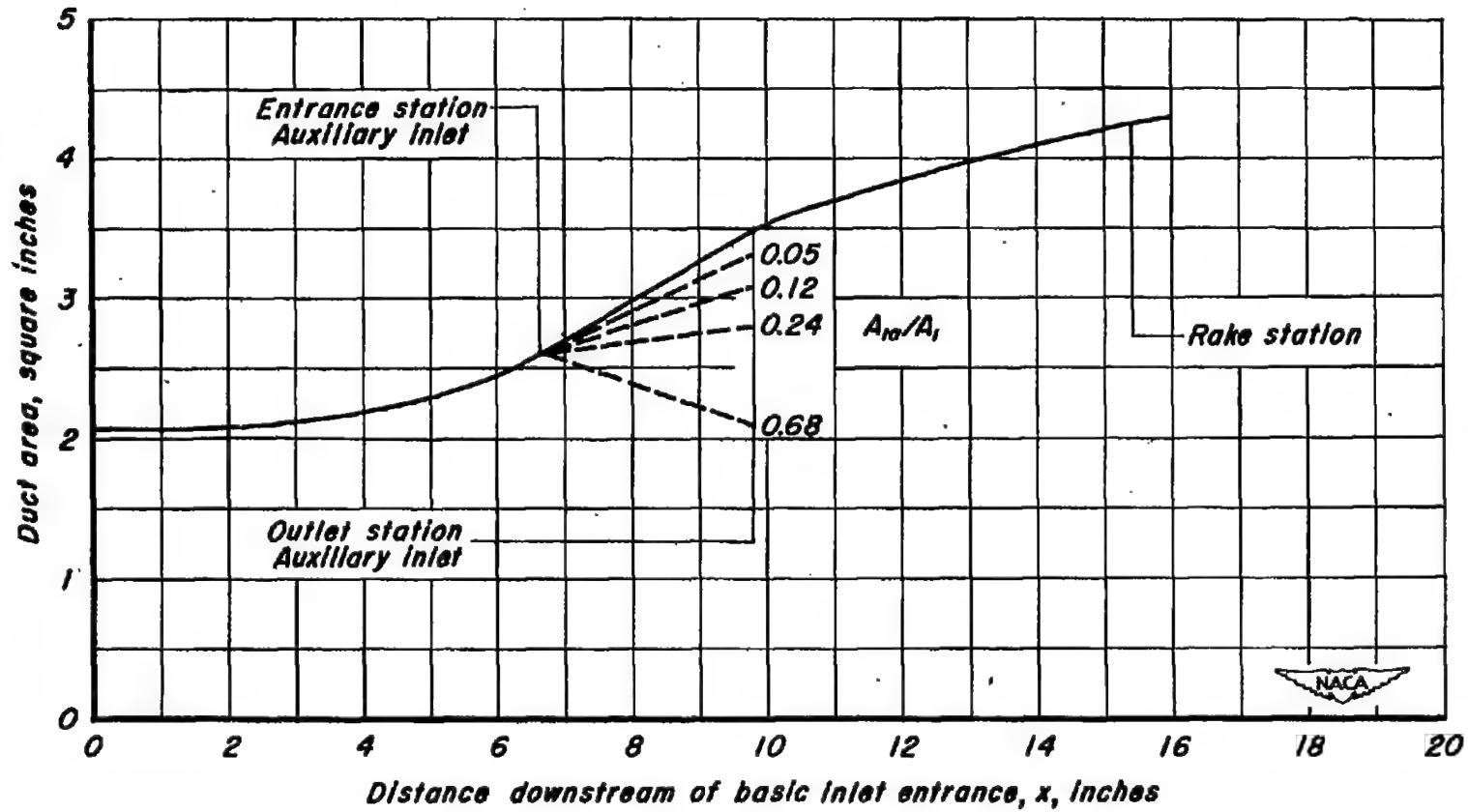


Figure 3.- Internal-duct-area variation.

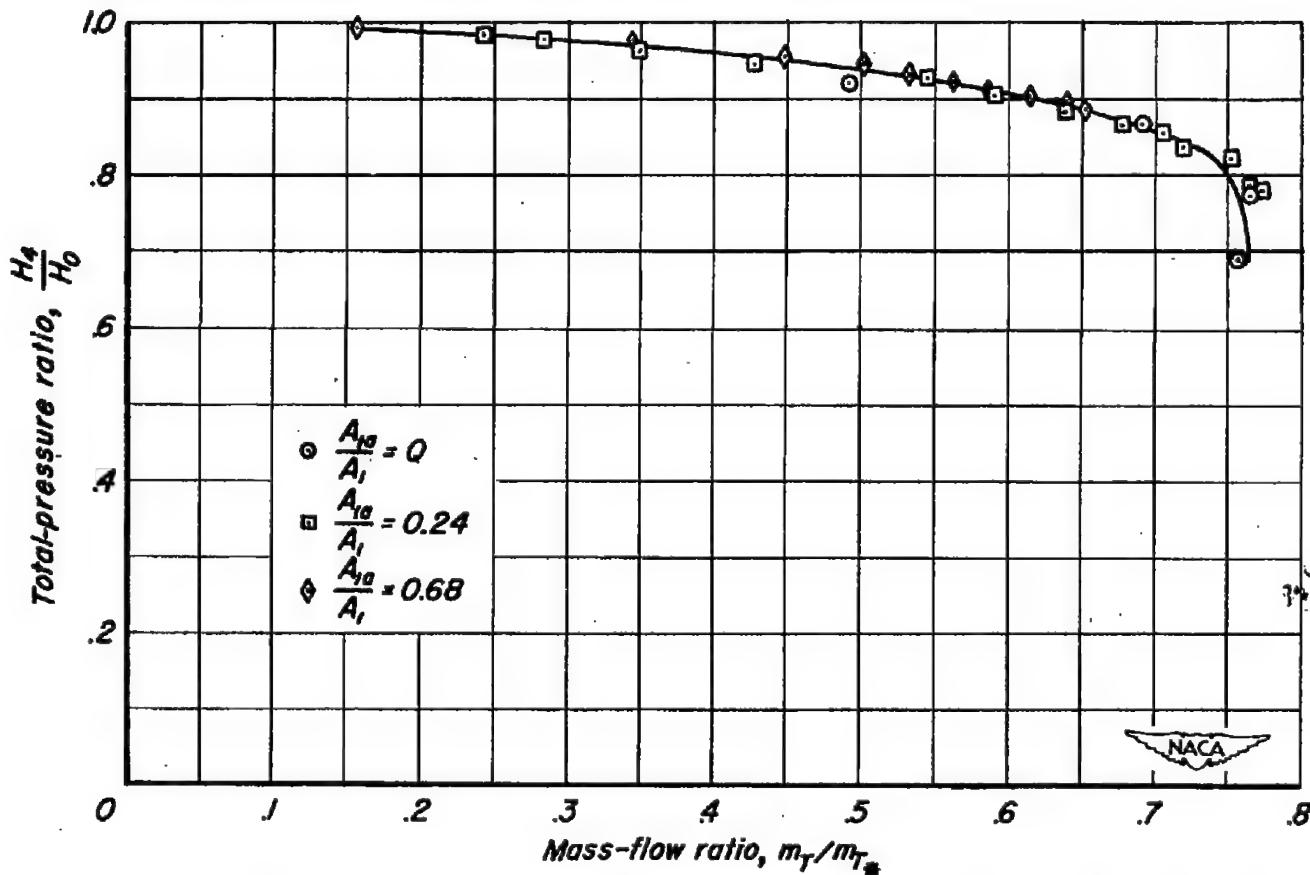


Figure 4. - Variation of total-pressure recovery with mass-flow ratio (referred to maximum theoretical mass flow through total inlet area), $M_\infty=0$, $\alpha=0$.

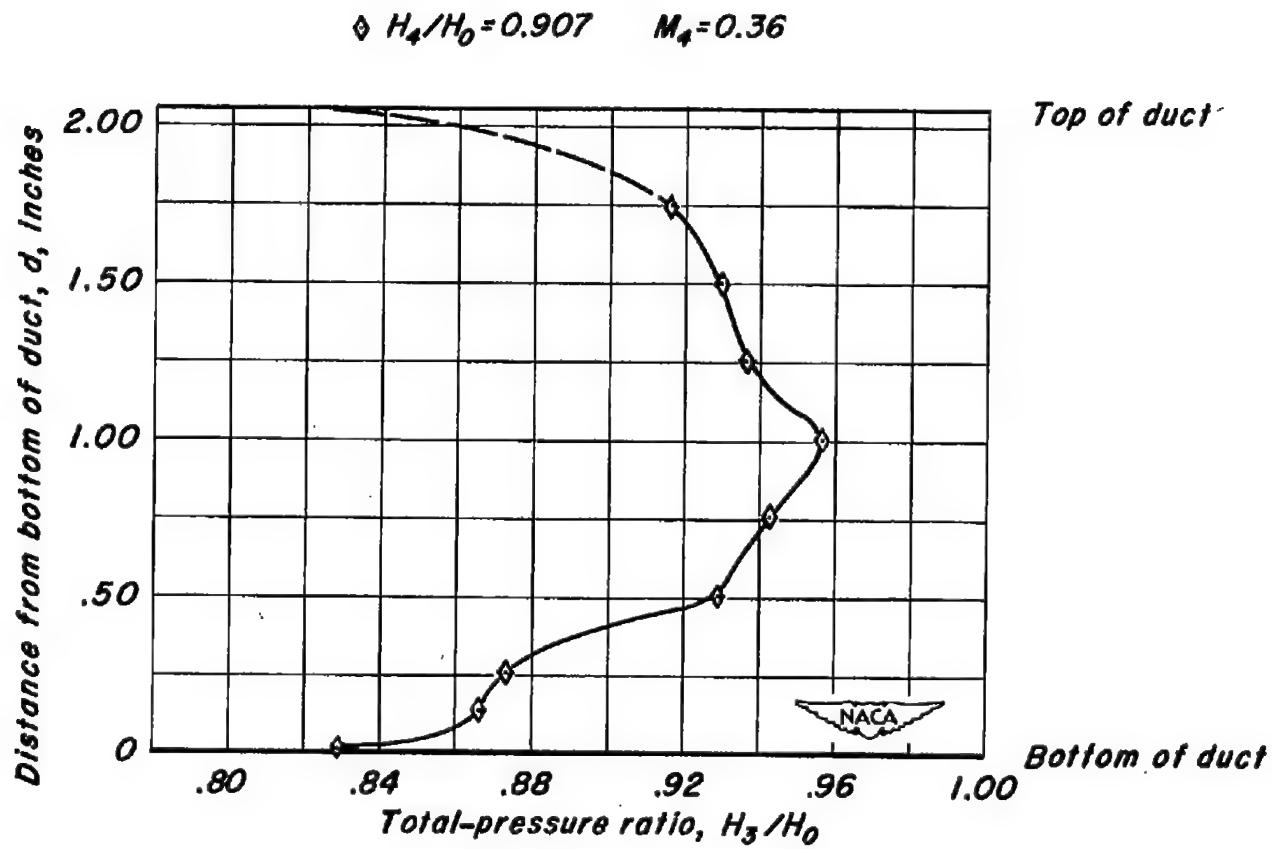


Figure 5. - Total-pressure profile at station 15.38 for $A_m/A_t = 0.68$ at free-stream Mach number 0 and $\alpha = 0^\circ$.

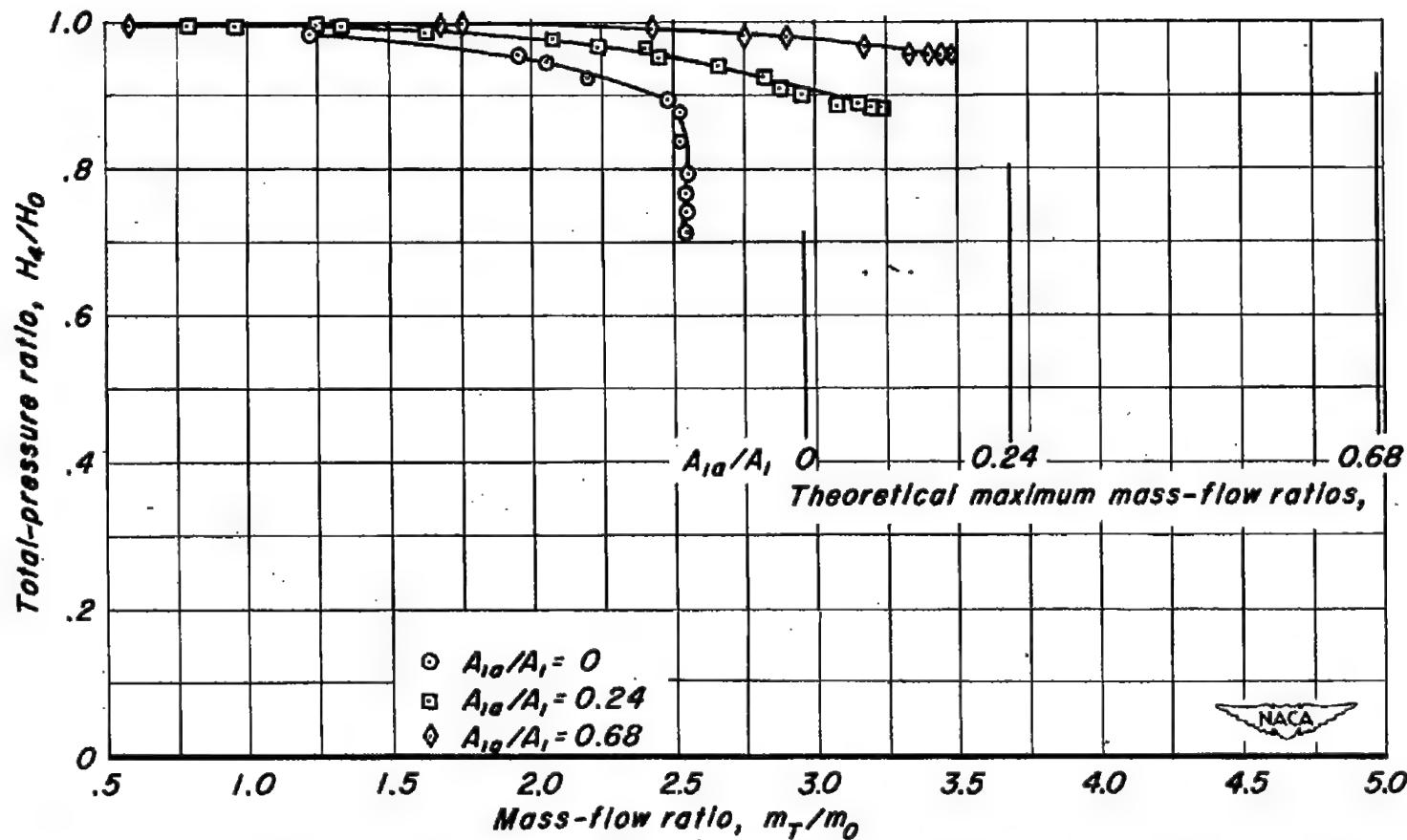


Figure 6. - Variation of total-pressure recovery with mass-flow ratio for three auxiliary inlet settings at Mach number 0.20 and $\alpha = 0^\circ$.

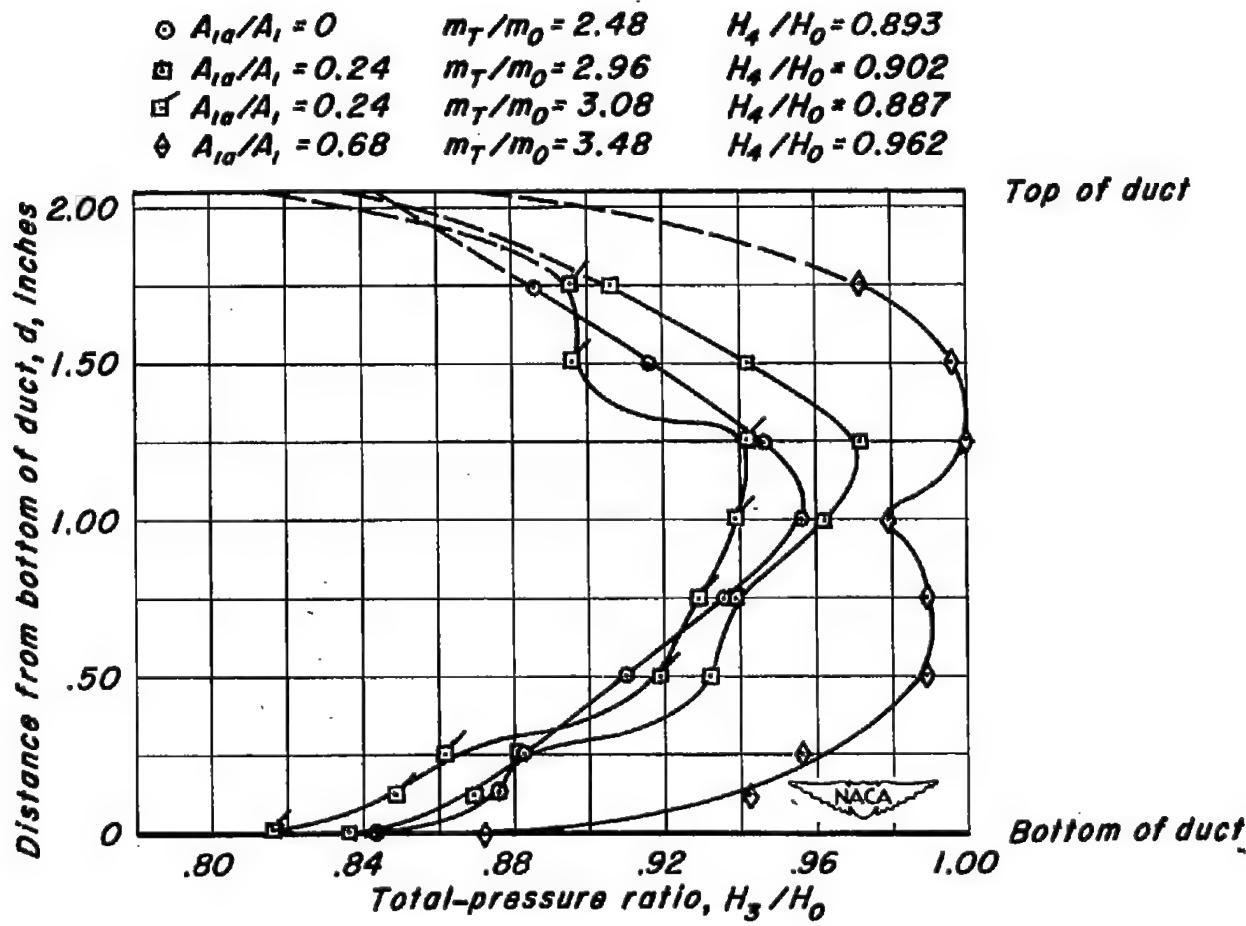


Figure 7. - Total-pressure profiles at station 15.38 for three auxiliary inlet settings at free-stream Mach number 0.20 and $\alpha = 0^\circ$.

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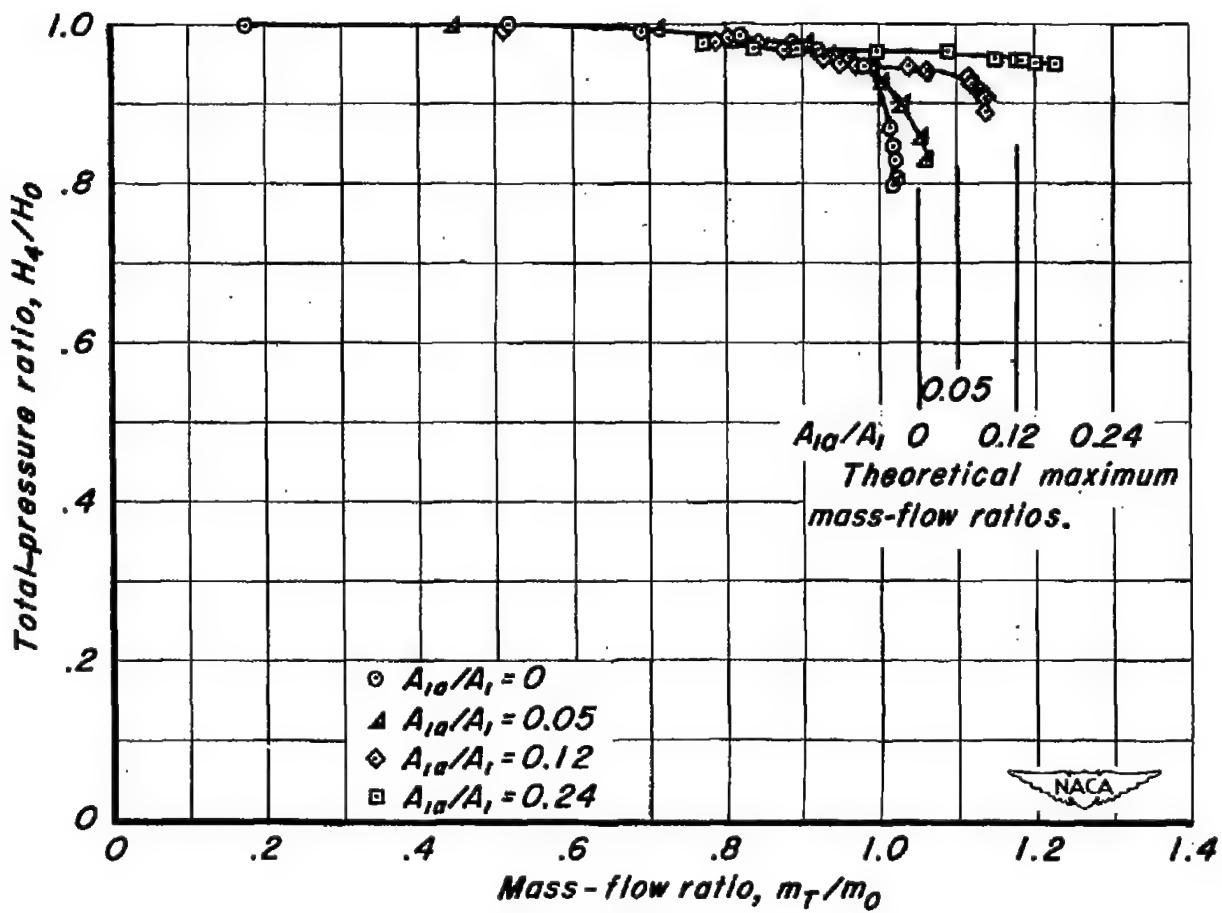


Figure 8. - Variation of total-pressure recovery with mass-flow ratio for four auxiliary inlet settings at Mach number 0.77 and $\alpha = 0^\circ$.

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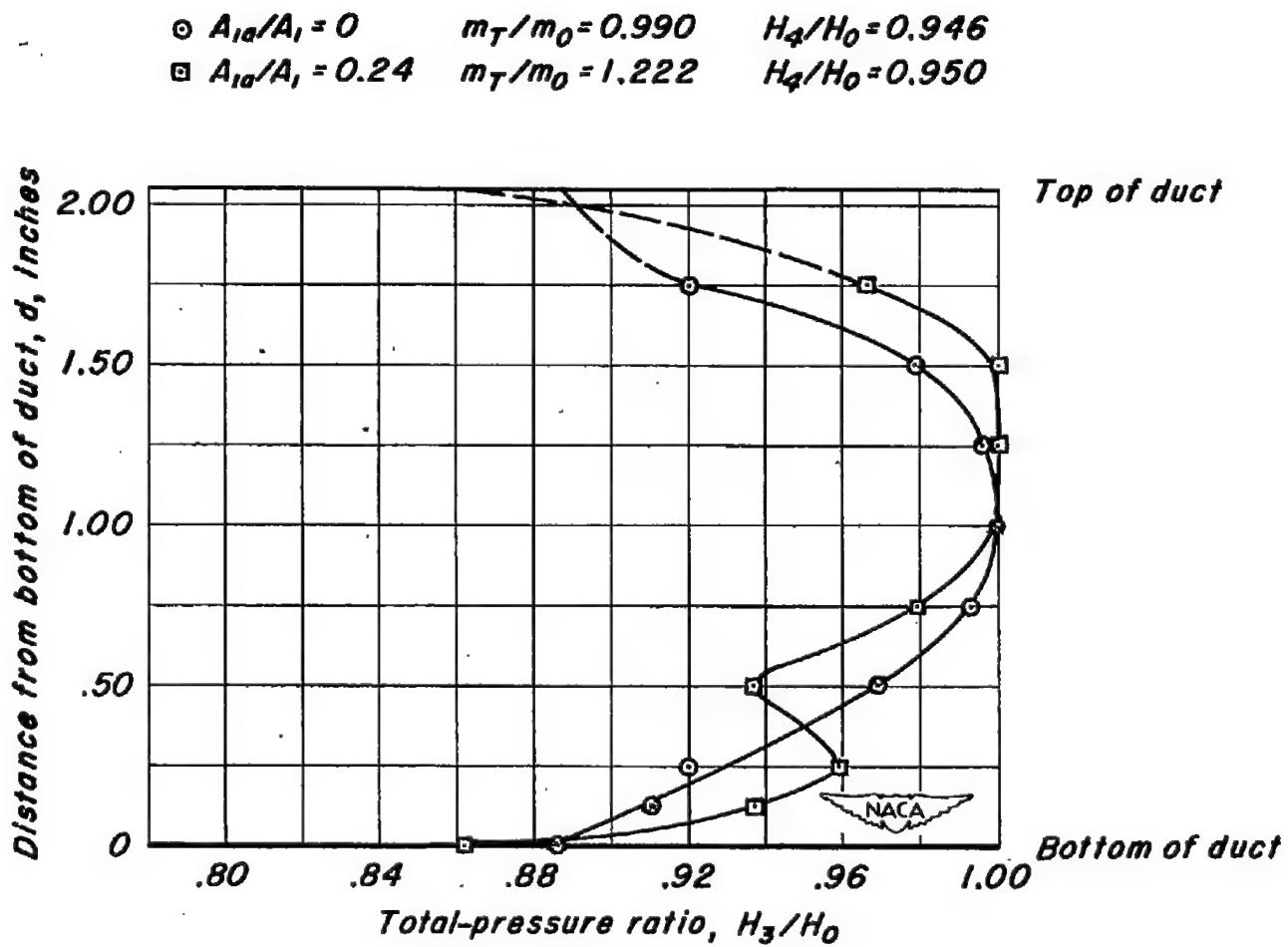


Figure 9. - Total-pressure profiles at station 15.38 for two auxiliary inlet settings at free-stream Mach number 0.77 and $\alpha = 0^\circ$.

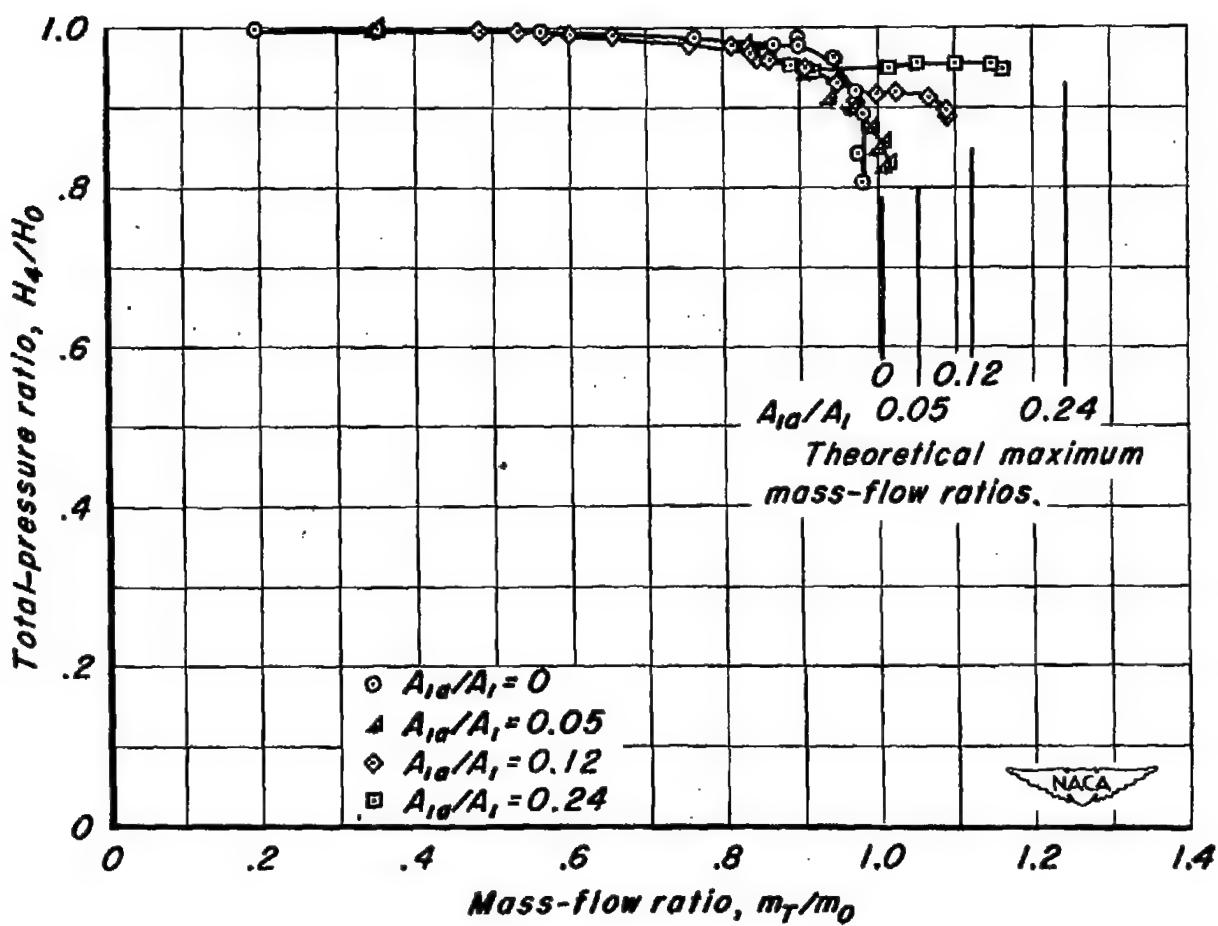


Figure 10. - Variation of total-pressure recovery with mass-flow ratio for four auxiliary inlet settings at Mach number 0.95 and $\alpha = 0^\circ$.

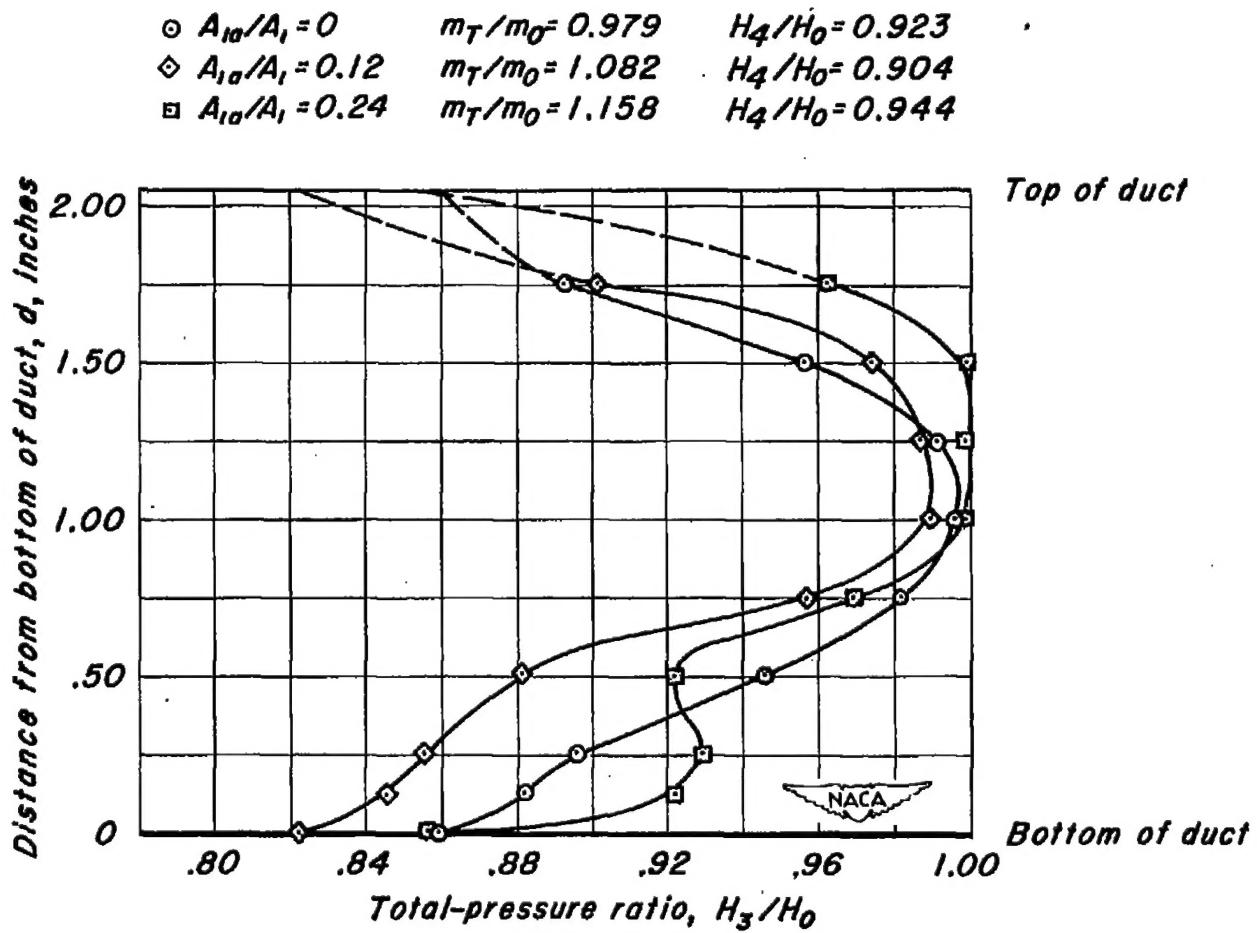


Figure 11. - Total-pressure profiles at station 15.38 for three auxiliary inlet settings at free-stream Mach number 0.95 and $\alpha = 0^\circ$.

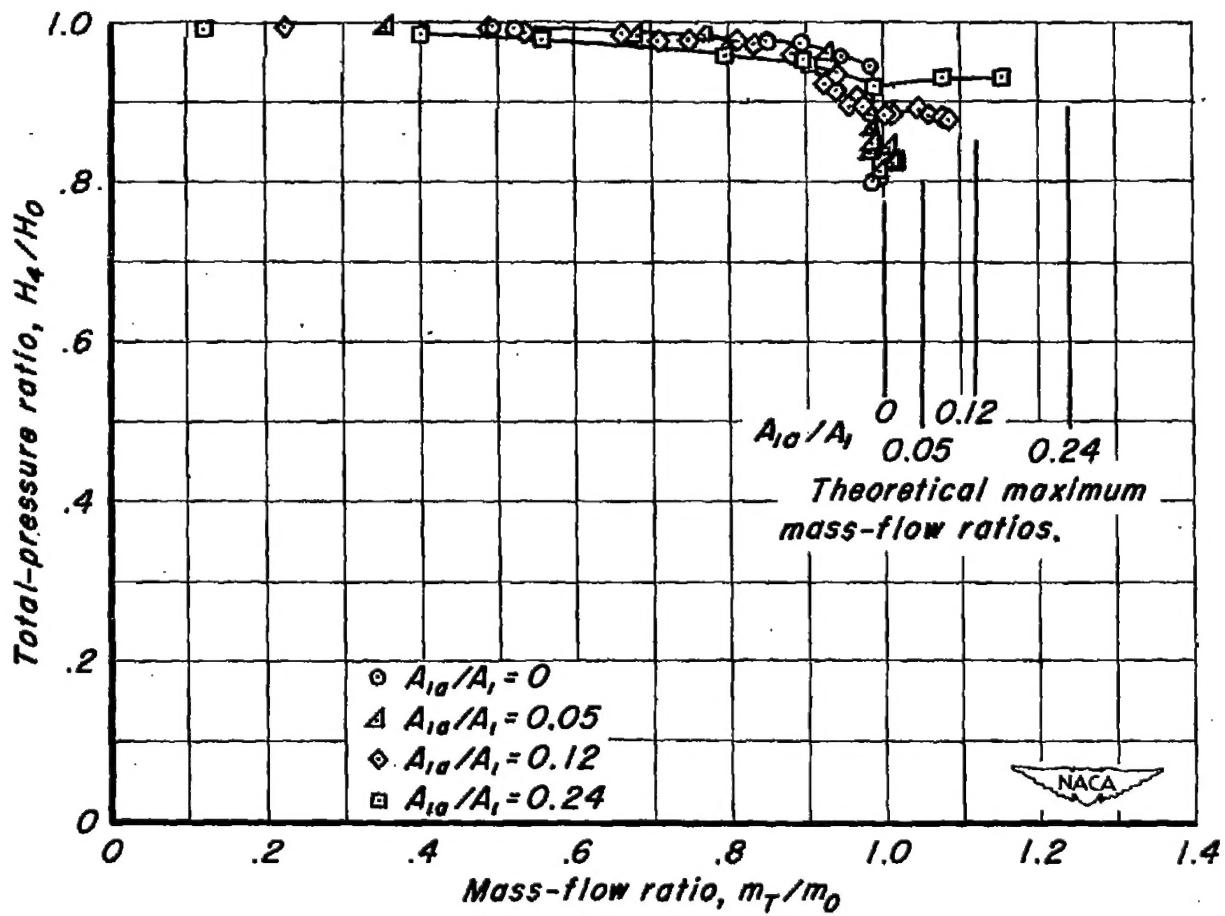


Figure 12. - Variation of total-pressure recovery with mass-flow ratio for four auxiliary inlet settings at Mach number 1.13 and $\alpha = 0^\circ$.

AUXILIARY INLET

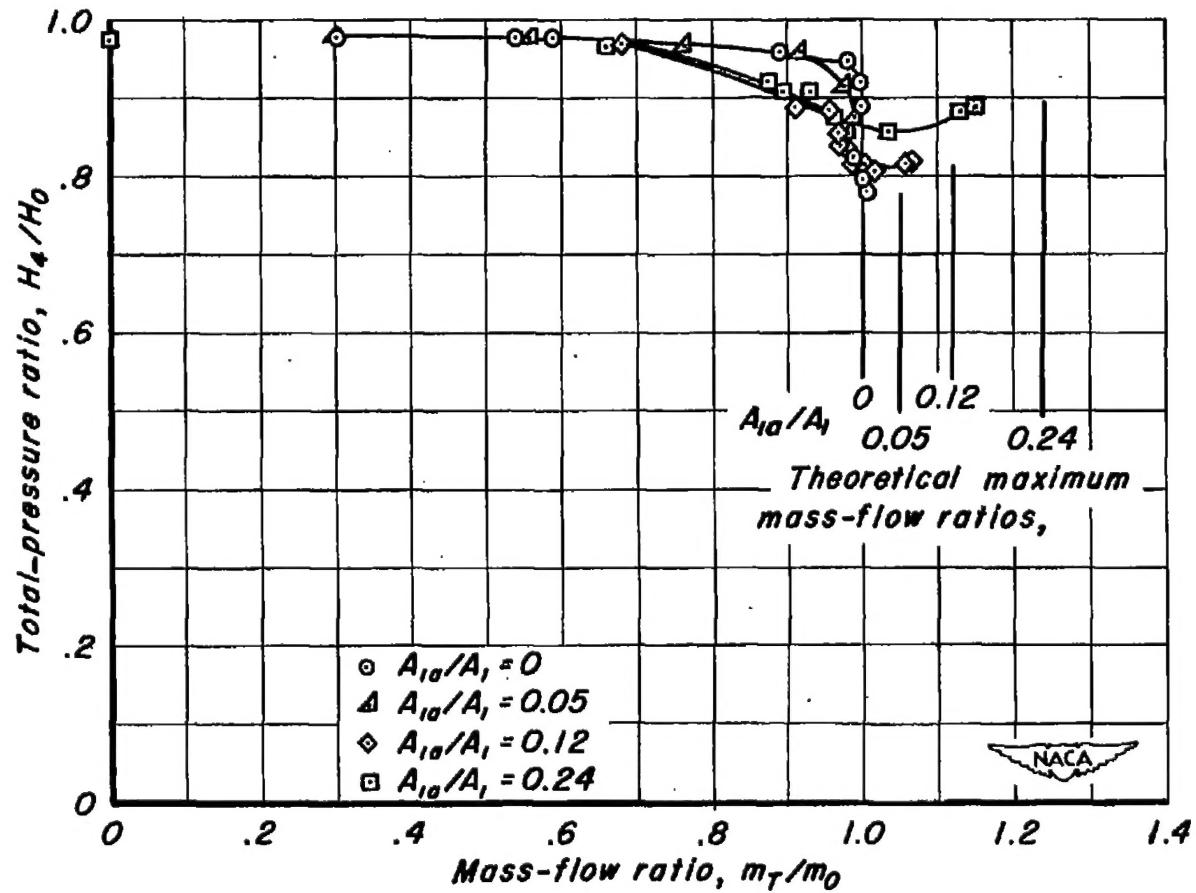


Figure 13. - Variation of total-pressure recovery with mass-flow ratio for four auxiliary inlet settings at Mach number 1.30 and $\alpha = 0^\circ$.

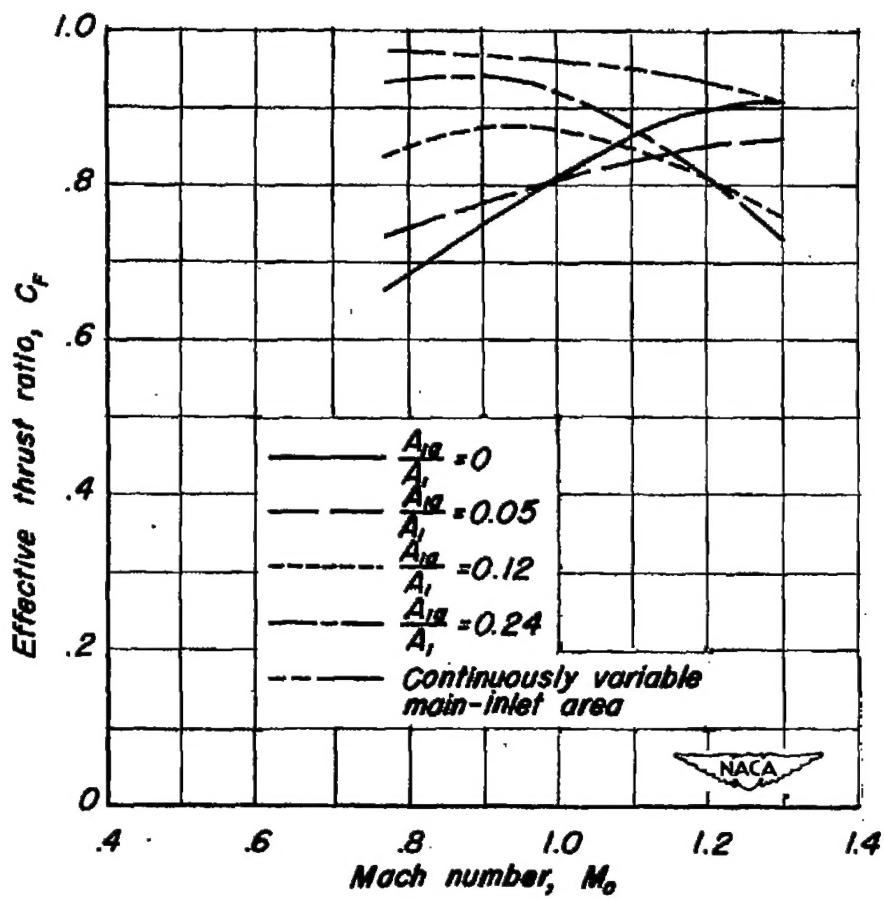


Figure 14.—Variation of effective thrust with Mach number for four auxiliary inlet openings and a continuously variable area inlet. Main inlet designed for 1.3 Mach number at 35,000 feet